This is the thermal band option addendum to the "Imagery Requirements" section of the Space Segment Requirements Document.

June 22, 2006 Version
Draft

5.8 LDCM Thermal Band Option Requirements

The requirements in this section are for a separate design and cost option as per 427-XXX, LDCM Space Segment Statement of Work.

5.8.1 LDCM Thermal Data Processing Algorithms

The requirements of Section 5.3, except 5.3.1.3, shall apply to the thermal bands.

5.8.1.1 Conversion to Temperature

The conversion to temperature algorithm shall take the calibrated radiance for each detector and convert it to TOA temperature.

5.8.2 LDCM Thermal Spectral Bands

5.8.2.1 Spectral Band Widths

5.8.2.1.1 Full-Width-Half-Maximum Points

The FWHM points of the relative spectral radiance response curve for each band shall fall within the range of the minimum lower band edge and the maximum upper band edge as listed in Table 5.8.2-1.

5.8.2.1.2 Center Wavelength

The center wavelength listed in Table 5.8.2-1 for each spectral band shall be located (within the associated tolerance listed in Table 5.8.2-1) halfway between the FWHM points of the actual relative spectral radiance response curve for each spectral band.

Table 5.8.2-1 Thermal Spectral Bands and Bandwidths

#	Band	Center Wavelength (nm)	Center Wavelength Tolerance (±nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)
10	Thermal 1	10800	200	10300	11300
11	Thermal 2	12000	200	11500	12500

5.8.2.2 Spectral Band Shape

5.8.2.2.1 Spectral Flatness

5.8.2.2.1.1 Flatness Between Band Edges

The system relative spectral radiance response between the lower band edge (lowest wavelength with 0.5 response) and the upper band edge (highest wavelength with 0.5 response) is required to have the following properties:

5.8.2.2.1.1.1 Average Response
The average relative spectral radiance response shall be greater than 0.8.

5.8.2.2.1.1.2 Minimum Response
No relative spectral radiance response shall be below 0.4.

5.8.2.2.1.2 Flatness Between 0.8 response points
The system relative spectral radiance response between the minimum wavelength with a 0.8 response and the maximum wavelength with a 0.8 response point shall always exceed 0.7.

5.8.2.2.2 Out of Band Response
The ratio of the integrated relative spectral radiance response which is outside the 0.01 response points and between 3000 and 20000 nm to the integrated relative spectral radiance response which is between the 0.01 response points shall be less than 2%. The ratio of the integrated relative spectral radiance response which is outside the 0.01 response points and below 3000 nm to the integrated relative spectral radiance response which is between the 0.01 response points shall be less than 0.5%. The integrated responses will be weighted by the radiance from a 300K blackbody summed with the radiance from a Lambertian surface of 100% reflectance illuminated by the sun at a zenith angle of 30°. The MODTRAN 4 (reference 2) "Chkur" solar spectrum shall be used for this calculation. The 0.01 response points are the points closest to the center wavelength where the response first drops to 0.01 of the peak response on each side of the center wavelength. Electrical crosstalk is not included within this requirement.

5.8.2.2.3 Relative Spectral Response - Edge Slope

5.8.2.2.3.1 Wavelength Intervals – Case 1
The wavelength interval between the first 0.05 and the first 0.50 relative response points and the last 0.50 and the last 0.05 relative response points shall not exceed the values in Table 5.8.2.2.3-1.

5.8.2.2.3.2 Wavelength Intervals – Case 2
The wavelength interval between the 0.01 relative response points and the corresponding 0.50 response band edge shall not exceed the values in Table 5.8.2.2.3-1.

Table 5.8.2.2.3-1 Spectral Edge Slope Intervals for Thermal bands

#	Band	Lower Edge Slope Interval 0.01 to 0.50* (nm)	Lower Edge Slope Interval 0.05 to 0.50* (nm)	Upper Edge Slope Interval 0.50 to 0.05* (nm)	Upper Edge Slope Interval 0.50 to 0.01* (nm)
10	Thermal 1	300	200	200	300
11	Thermal 2	300	200	200	300

*Normalized to peak spectral response for the band

5.8.2.3 Spectral Uniformity
Within a band, all detector measured FWHM bandwidths shall be within ±5% of the measured mean FWHM bandwidth. Additionally, see Section 5.8.4.2.3.

5.8.2.4 Spectral Stability
Band center wavelengths and band edges shall not change by more ± 50 nm over the life of the mission.

5.8.2.5 Spectral Band Simultaneity

For any point within a single scene observed by the LDCM, the LDCM shall acquire data for all spectral bands within a six-second period.

5.8.3 LDCM Thermal Spectral Band Spatial Resolution

5.8.3.1 Thermal Band Ground Sample Distance

Space segment sensor data shall provide a pixel-to-pixel increment, in the in-track and cross track directions, equivalent to a GSD 120m or less for both thermal bands across the WRS-2 scene.

5.8.3.2 Thermal Band Edge Response Slope
The relative edge response slope for the thermal bands after radiometric correction per 5.3.1.2 (slope between 40% and 60% response points, see Figure 5.5-1) shall exceed 0.005/meter in the in-track direction and 0.007/meter in the cross-track direction across the entire Field-of-View. The edge response, as used here, is the normalized response of the imaging system to an edge. That is, the edge response is normalized so that the mean minimum edge response is set to zero and the mean maximum response is set to 100%.

5.8.3.3 Thermal Band Edge Response Uniformity
The relative edge response slope shall not vary by more than 10% (maximum deviation from the band average, 100%*(max - avg) / avg) in any band across the Field-of-View and by not more than 20% (maximum deviation from the two-band average) between the LDCM spectral bands 10 and 11 (thermal bands).

5.8.3.4 Thermal Band Edge Response Overshoot and Aliasing
The requirements of 5.5.2.3 and 5.5.3 shall apply to the thermal bands.

5.8.3.5 Thermal Band Stray Light Rejection and Internal Scattering (TBR)
The effectiveness of the rejection of stray light in the Space Segment thermal sensor data is defined in terms of a scene with the following characteristics: The Space Segment sensor data are collected from a circular region having a radius of 0.25 degrees and having a uniform target radiance = LT. That target region is surrounded by an annular region having an inner radius of 0.25 degrees and an outer radius of 25 degrees and having a uniform background radiance = LB.

When LB = LT, the Space Segment instrument radiance measured at the center of the target region has a nominal value = LT. When LB is not equal to LT, the magnitude of the change in measured Space Segment instrument radiance at the center of the target region shall be less than 0.004 times the magnitude of the difference between LB and LT. This requirement applies to both spectral bands for the duration of the nominal Space Segment instrument mission for target and background radiance levels ranging from a minimum of zero to a maximum L_{Max} (the radiance corresponding to 360K), such that LT - L B ranges from a minimum of - L_{Max} to a maximum of L_{Max}. (See L_{Max} in the table 5.8.4.2.1-1)

5.8.3.6 Thermal Band Ghosting

An extended object at a radiance level equivalent to a blackbody temperature of 500K (TBR) anywhere in the Space Segment instrument telescope full FOV, shall not produce a significant (as described below) ghost image anywhere in the active detectors area of the focal-plane. This requirement applies to both bands across the entire focal plane.

A ghost image is either a secondary image of an object for objects within the FPA FOV or a primary image of an object for objects that are outside the FPA FOV. In either case the ghost appears as either an attenuated rendition of the original object or a blurred and attenuated version of the original object. A ghost also has a constant displacement vector from the original image. A significant ghost is defined as an image artifact when its peak signal after radiometric calibration is above the radiance corresponding to 0.4K at 300K for that band.

5.8.4 LDCM Thermal Spectral Band Radiometry

5.8.4.1 Absolute Radiometric Accuracy

The thermal band absolute radiometric uncertainty requirements are given in Table 5.8.4.1-1 with all uncertainties established relative to National Institute for Standards and Technology (NIST) standards. This requirement applies to extended, spatially uniform, unpolarized targets. Uncertainty estimates include the NIST standard uncertainties.

Table 5.8.4.1-1 Thermal Bands Absolute Radiometric Uncertainty Requirements

Equivalent Blackbody Temperature Range	Radiance Uncertainty (1-sigma)
260 K – 330 K	2%
240K - 260K; 330K - 360K	4%

5.8.4.2 Radiometric Precision

5.8.4.2.1 Pixel Noise Equivalent Delta Temperatures

The median Noise Equivalent Delta Temperatures (NEΔT) required for each thermal band are listed in Table 5.8.4.2.1-1 and 5.8.4.2.1-2. Any pixel with an NEΔT greater than 1.25 times these values shall be considered out-of-specification per paragraph 5.6.7.4.

Table 5.8.4.2.1-1 Temperatures for Noise and Saturation for Thermal Bands

#	Band	Temperatures for NEΔT (K)		Saturation Temperatures (K)	Saturation Radiances (W/m^2 sr μm)
		Typical, $T_{Typical}$	High, T_{High}	T_{Max}	L_{Max}
10	Thermal 1	300K	320K	360K	20.5
11	Thermal 2	300K	320K	360K	17.8

Table 5.8.4.2.1-2 Noise Equivalent Delta Temperatures (NEΔT) and Radiances (NEΔL) for Thermal Bands [TBR]

#	Band	NEΔT Requirements		NEΔL Requirements (W/m^2 sr μm)
		At $T_{Typical}$	At T_{High}	At $T_{Typical}$, T_{High}
10	Thermal 1	0.4K	0.35K	0.059
11	Thermal 2	0.4K	0.35K	0.049

5.8.4.2.2 Quantization Noise Limit

Thermal band data NEΔT performance shall not be quantization noise limited at $T_{typical}$ and above, i.e., system noise is greater than or equal to 0.5 Digital Number, unless meeting this requirement would force greater than 12 bit quantization.

5.8.4.2.3 Pixel-to-Pixel Uniformity

The following environmental conditions and measurement approach shall apply to requirements 5.8.4.2.3.1, 5.8.4.2.3.2, and 5.8.4.2.3.

- The thermal band banding requirements shall apply to uniform sources with the radiance corresponding to a blackbody temperature above 260K and below 330 K.
- The thermal band radiometric values shall be corrected per paragraph 5.3.1.2.
- The thermal band temporal noise shall be averaged to verify compliance with this specification.

5.8.4.2.3.1 Full Field of View

The standard deviation of the radiometrically corrected values across all pixels within a line of each thermal band shall not exceed 0.5% of the average radiance.

5.8.4.2.3.2 Banding (TBR)

a. The root mean square of the deviation from the average radiance across the full line for any 100 contiguous pixels within a line of radiometrically corrected values within a band shall not exceed 0.5% of that average radiance. See section 5.6.2.3.2a for the equation defining this banding parameter.

b. The standard deviation of the radiance across any 100 contiguous pixels within a line of radiometrically corrected data within a band shall not exceed 0.5% of the average radiance across the full line. The average radiance across the line (FOV) is used here merely as a reference for deriving the magnitude of the 0.5%. The mean in the standard deviation calculation is, by definition, the mean of the 100-pixel sample set and not the entire FOV mean. See section 5.6.2.3.2b for the equation defining this banding parameter.

5.8.4.2.3.3 Streaking

The maximum value of the streaking parameter within a line of radiometrically corrected, thermal band data shall not exceed 0.005[TBR]. See section 5.6.2.3.3 for the equation defining this streaking parameter.

5.8.4.2.4 Coherent Noise

The requirements of Section 5.6.2.4 shall apply to the thermal bands.

5.8.4.3 Saturation Temperatures

The thermal band shall detect, without saturating, signals from the noise floor (NEΔL in Table 5.8.4.2.1-2) up to the radiance corresponding to T_{Max} as shown in Table 5.8.4.2.1-1.

5.8.4.4 Radiometric Stability

Thermal band data for all pixels, after radiometric calibration per 5.3.1.2, for radiometrically constant targets with radiances greater than or equal to the radiance of a $T_{Typical}$, shall not vary by more than plus or minus 0.7% (1-sigma) of their radiance over a 10 minute period. Pixels failing this specification are considered out-of-specification and are subject to the limitations of paragraph 5.6.7.4.

5.8.4.5 Image Artifacts

5.8.4.5.1 Bright Target Recovery

The thermal band data shall be such that for an image pixel that has been exposed to a pixel-sized area at a radiance level of less than or equal to that corresponding to a blackbody temperature of 500K (TBR), the pixels outside the 11 x 11 region around that pixel are not altered by more than 1% of their radiance at or above $T_{Typical}$.

5.8.4.5.2 Pixel-to-Pixel Crosstalk

The thermal band data shall be such that the electrical crosstalk-induced artifacts in pixels caused by regions of pixels having radiance levels less than the saturation level and

which are more than ten pixels away shall not exceed 1% of the affected pixels' radiances at or above $T_{Typical}$, after radiometric correction.

5.8.4.6 Dead, Inoperable and Out-of-Specification Pixels

The requirements of 5.6.7 shall apply to the thermal bands.

5.8.5 LDCM Thermal Band Geometric Precision, Geolocation and Cartographic Registration

The following sections detail the LDCM thermal band image geometric accuracy requirements that must be achieved when the correction algorithms provided in accordance with section 5.3.0 of this specification are applied to LDCM Space Segment sensor and ancillary data (LDCM data). The specific correction algorithms that apply to each geometric imagery requirement are shown in table 5.8.5-1.

Table 5.8.5-1 Thermal Band Image Requirement to Processing Algorithm Verification Mapping

	5.3.1 Radiometric Correction	5.3.2.1 Ancillary Data Processing	5.3.2.2 Line-of-Sight (LOS) Model Creation	5.3.2.3.1 LOS Projection to WGS84 Ellipsoid Surface	5.3.2.4 LOS Model Precision Correction	5.3.2.3.2 LOS Projection to Terrain Surface	5.3.2.5 Image Resampling
5.8.5.1 Thermal Band Registration Accuracy	X	X	X	X	X	X	X
5.8.5.2 Thermal Band Image-to-Image Registration Accuracy	X	X	X	X	X	X	X
5.8.5.3 Thermal Band Geodetic Accuracy	X	X	X	X			X
5.8.5.4 Thermal Band Geometric Accuracy	X	X	X	X	X	X	X

5.8.5.1 Thermal Band Registration Accuracy

5.8.5.1.1 Thermal Band-to-Band Registration

Corresponding pixels from the two thermal bands in LDCM data that have been geometrically corrected, including compensation for the effects of terrain relief shall be co-registered with an uncertainty of 24meters or less in the line and sample directions at the 90% confidence level.

5.8.5.1.2 Thermal Band to Multispectral Band Registration

Corresponding pixels from the thermal bands in LDCM data that have been geometrically corrected, including compensation for the effects of terrain relief shall be co-registered to LDCM bands 1-9 with an uncertainty of 30 meters or less in the line and sample directions at the 90% confidence level. This multi-resolution co-registration refers to the distance between the centroid of a thermal pixel and the centroid of the aggregate of the reflective pixels that yield the same nominal resolution.

5.8.5.2 Thermal Band Image-to-Image Registration Accuracy

Two LDCM thermal band data sets of the same area, acquired on different dates, that have been geometrically corrected, including compensation for the effects of terrain relief, shall be capable of being co-registered by a lateral (line and/or sample) shift with no rotation or other distortion, with an uncertainty less than or equal to 45 meters, in the line and sample directions at the 90% confidence level when image-to-image correlation is applied to data from the same spectral band.

5.8.5.3 Thermal Band Geodetic Accuracy

5.8.5.3.1 Thermal Band Absolute Geodetic Accuracy

The pixels for targets at the Earth's topographic surface in geometrically corrected LDCM thermal band data shall be located relative to the WGS84 geodetic reference system, G873 or current version, with an uncertainty less than or equal to 76 meters (90% circular error), excluding terrain effects. This specification applies to the horizontal error of ground control points measured in the processed image, after compensation for control point height.

5.8.5.3.2 Thermal Band Relative Geodetic Accuracy

The pixels for targets at the Earth's topographic surface in geometrically corrected LDCM data shall be located relative to the WGS84 geodetic reference system, G873 or current version, with an uncertainty less than or equal to 48 meters (90% circular error), excluding terrain effects, over a WRS-2 scene, after the removal of constant offsets.

5.8.5.4 Thermal Band Geometric Accuracy

The pixels for targets at the Earth's topographic surface in daytime LDCM data that have been geometrically corrected, including pointing refinement using ground control and terrain compensation using digital elevation data, shall be located relative to the WGS84 geodetic reference system, G873 or current version, with an uncertainty less than or equal to 42meters (90% circular error), including compensation for terrain effects.

Reference:
2) A. Berk, G.P. Anderson, P.K. Acharya, J.H. Chetwynd, L.S. Bernstein, E.P. Shettle, M.W. Matthew, and S.M. Adler-Golden, MODTRAN4 USER'S MANUAL, AIR FORCE RESEARCH LABORATORY, Space Vehicles Directorate AIR FORCE MATERIEL COMMAND, HANSCOM AFB, MA 01731-3010, 1 June 1999.